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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01V 1/38, 1/20 — A1

(11) International Publication Number: WO 97/37246

(43) International Publication Date: 9 October 1997 (09.10.97)

(21) International Application Number: PCT/IB97/00309

(22) International Filing Date: 26 March 1997 (26.03.97)

(30) Priority Data:

08/625,766	29 March 1996 (29.03.96)	US
08/645,517	14 May 1996 (14.05.96)	US

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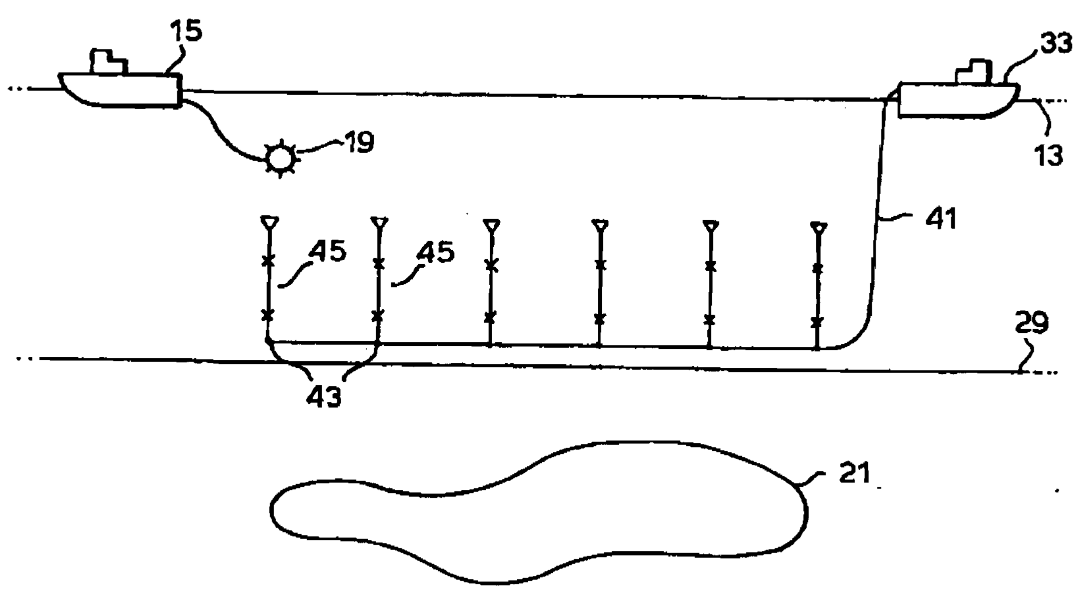
(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published

With international search report.

(54) Title: BOTTOM-REFERENCED SEISMIC CABLE WITH VERTICAL HYDROPHONE ARRAYS



(57) Abstract

A bottom-referenced cable system for marine seismic exploration includes a bottom-referenced cable (41) adapted to be deployed on the water bottom (29). The cable (41) has multiple take-outs (43) at intervals thereof, and multiple vertical pressure sensor arrays (45) each connected to the cable (41) at one of the take-outs (43). Each vertical pressure sensor array (45) has at least a lower pressure sensor (49L) and an upper pressure sensor (49U) disposed in vertical spaced relation, and a float (47) for maintaining its vertical orientation.

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BOTTOM-REFERENCED SEISMIC CABLE WITH VERTICAL HYDROPHONE ARRAYS

Field of the Invention

This invention relates to cables for use in marine seismic exploration.

Background of the Invention

Marine seismic exploration is an extremely important tool for the location of off-shore reserves. Marine seismic exploration is usually conducted in one of two ways: with a towed streamer or with a bottom-referenced cable. As illustrated in prior art Fig. 1, marine seismic surveys using towed streamers are usually conducted by towing at least one streamer 11 at a given depth below the surface 13 of the water from a vessel 15. The streamer 11 is equipped with a plurality of pressure sensors 17, such as hydrophones, disposed at intervals along he streamer. Acoustic energy is generated in the vicinity of the streamer using an air gun array or a marine vibrator array 19. The source wavelet travels downward through the earth, and is partially reflected by subsurface layers (formation 21 in the Fig. 1) that present an acoustic impedance contrast. The primary reflected wavelet 23 travels upwardly from the subsurface layer, and the pressure waves generated by the upward-travelling reflection are detected by the pressure sensors 17.

Seismic exploration using towed streamers is complicated by secondary waves such as wave 25, known as ghosts, that are received by the pressure sensors 17 as downward-travelling reflections after reflecting off the air/water boundary at the surface 13. The air/water boundary is an efficient reflector, and thus the ghosts are difficult if not impossible to differentiate from the primary waves. These ghosts adversely affect the data obtained during the exploration by attenuating certain frequencies. Seismic exploration using towed streamers is further complicated by multiple reflections such as wave 27, which are detected by the pressure sensors after reflecting off multiple boundaries such as the subsurface formation 21, the air/water boundary 13, and the sea floor 29.

A marine seismic survey using a bottom-referenced cable is illustrated in prior art Fig. 2. Surveys using bottom-referenced cables are typically employed in areas populated with numerous obstacles, such as drilling and production platforms. In this technique, several miles of bottom cables 31 (only one shown in the figure) are deployed along the sea floor 29 by a vessel 33. The bottom cable 31 is provided with sensors 35, comprising pressure sensors (e.g., hydrophones) and particle velocity sensors (e.g., geophones) at regular intervals along the cable. Typically, each sensor location along the cable has two channels, and two hydrophones (connected in parallel) per channel and two gimbal geophones (connected in series) are deployed at each location. The depth of deployment for the dual sensor bottom cable may be from ten meters to a hundred meters or more, depending upon how difficult it is to deploy the cables in deep water.

As with the streamer technique, the primary wave 23 is reflected from the subsurface formation 21 and is received as an upward-travelling wave by the sensors 35. Ghost 25 is detected by the sensors as a downward-travelling wave, and is even more of a problem in the bottom-referenced cable technique because, when the water depth is large, the spectral ghost notches fall in the seismic frequency band and drastically effect the seismic resolution. Resolution is further complicated by multiple reflection waves such as wave 27.

The purpose of using both hydrophones and geophones in the bottom-referenced cable is to capitalize on the differences between these two types of sensors (their responses to the ghost are 180° out of phase) to attenuate the ghost signals. However, as explained in more detail below, the geophone response tends to be quite noisy, and thus using the response to attempt to remove the ghosts results in an overall reduction in resolution and quality of the data.

Fig. 3a illustrates amplitude versus time hydrophone response at the water bottom. V indicates the normal incidence transmission coefficient, and the horizontal axis is time. The primary reflection has the amplitude V and it arrives at a certain time which can be considered the time origin for the subsequent reverberations. Time (t_1) from this origin is equal to the distance travelled through the water divided by the water propagation velocity, i.e., the time

for the primary reflection to travel to the surface where it is reflected, and after that to propagate back to the water bottom. The hydrophone response at time t_1 is -(l+r)V where r is the water bottom reflectivity. This is the first order reverberation. The second water reverberation arrives at time t_2, a multiple of time t_1, and the hydrophone response is r(l+r)V. The third order reverberation is recorded by the hydrophone at time t_3, a multiple of time t_1, with the amplitude r**2(l+r)V.

The geophone amplitude versus time response is shown in Fig. 3b. The primary reflection arrives at the geophone at the same time as for the hydrohpone and the geophone response is V/z, where V is the normal incidence transmission coefficient and Z is a scaling factor. The first order reverberation is recorded by the geophone at the time t_1 with the amplitude (l-r)V/Z. The second order reverberation is recorded at the time t_2 with the amplitude -r(l-r)V/Z, and the third order reverberation is recorded at the time t_3 with the amplitude-r**2(l-r)V/Z.

From the amplitude versus time response of the hyrophone and the geophone we can notice that the primary reflections, upward-travelling, have the same polarity and the downward traveling reverberations, have opposite polarity.

Some ghost attenuation can be achieved by adding the hydrophone and the geophone signals together after the signals have been suitably scaled and phase corrected. Theoretically, the scale factor S=(l+r)/(l-r), where r is the water bottom reflectivity, should be applied to the geophone data. Determination of the water bottom reflectivity coefficient r depends upon the acoustic impedance of the bottom material. Thus, the scale factor S can vary among different receiver locations on the same cable.

There are several known methods for deriving the scale factors for geophone signals. U.S. Patent No.5,235,554 describes a method where a calibration survey is used to estimate the water bottom reflection coefficient. In such a calibration survey, a low energy source is fired over each receiver pair, and the scale factor is determined from the ratio of the peaks of the first arrivals of the hydrophone and geophone signals. Collection of this survey data requires additional time and cost over and above the data acquisition phase of the survey.

U.S. Patent 5,396,472 describes a method to derive the water bottom reflection coefficient that eliminates the need for a separate calibration survey. This method involves summing the pressure and velocity signals, multiplying the results by the inverse Backus operator, and then solving for the water bottom reflectivity r using an optimization algorithm. U.S.Patent 5,365,492 describes a method wherein the hydrophone signal is used first to adaptively remove noise from the geophone signal, and then the cleaned geophone signals are scaled by a scaling factor and added to the hydrophone signals. The resulting signal is then auto-correlated and the relative amplitude of the first auto-correlation function side lobe is measured. The optimum scale factor for the geophone data is then found by optimizing the value of the scale factor with respect to the first side-lobe amplitude of the auto-correlation. U.S. Patent 4,520,467 describes a general method of equalizing the amplitude spectra of the geophone data and the hydrophone data, correcting the phase spectra of the geophone and hydrophone data for instrument effects, and applying a spectral weighting function based on signal-to-noise ratio to the geophone and hydrophone data. U.S. Patent 4,520,467 does not describe the principles or theories upon which the equalization is performed.

In general, in all of the above techniques, the effectiveness of using the geophone response in removing ghost effects depends strongly on the signal-to-noise ratio of the geophone signal. Unfortunately, the quality of the geophone signal is highly dependent on the quality of the coupling between water bottom and the geophone. This varies widely from location to location. Even with good coupling, the velocity signals can be contaminated with elastic wave noise types that simply do not propagate significantly as pressure signals in the water layer. In extreme cases, when the signal to noise ratio is poor for the geophone data, the geophone data must be scaled down significantly before combination with the hydrophone data.

Often, the data obtained using the bottom-referenced dual sensor cable must be merged at a later time with data obtained using the streamer technique. If the geophone data are noisy, the merging operation becomes difficult or impossible.

Another method to reduce ghosting in marine seismic exploration is to deploy receivers in conjunction with many anchored buoys. This method is described in detail in Moldoveanu et al., "Digiseis-enhanced streamer surveys (DESS) in obstructed areas: A case

study of the Gulf of Mexico", Abstracts from SEG International Exposition, October 23-28, 1994. In general, in this method a pair of vertically spaced hydrophones are deployed near the anchor for each buoy. A wavefield separation technique is then used for deghosting. One such technique is described in Moldoveanu et al., "Undershooting Using The Vertical Hydrophone Array - The South Marsh Island Experiment", presented at the 63rd Annual Meeting, Society of Exploration Geophysicists, September, 1993. The wavefield separation technique capitalizes on the vertical separation of the two hydrophones to minimize the effects of the ghosts. The advantage of using multiple vertical hydrophone arrays over a hydrophone/geophone combination is that the data from the hydrophones are much better in quality than the data from the geophone. Also, the data are similar in quality and character among the different hydrophones, removing the need for elaborate matching procedures and making processing much easier. The disadvantage of this method, however, is that deployment of the anchored buoys is time-consuming and expensive compared to deployment of a cable on the sea floor. Also, because buoys are not linked to one another, an expensive radio telemetry system must be used to send the data back to a central recording system.

Summary of the Invention

The invention provides to a bottom-referenced cable system for marine seismic exploration which includes a bottom-referenced cable adapted to be deployed on the water bottom and a plurality of vertical pressure sensor arrays connected to the cable. Each of the vertical pressure sensor arrays further includes a lower pressure sensor and a upper pressure sensor disposed in vertical spaced relation, and means for maintaining vertical orientation of the vertical pressure sensor array.

In another aspect, the invention provides a method of obtaining marine seismic data, comprising the steps of:

deploying on the water bottom a cable having a plurality of vertical pressure sensor arrays connected at intervals thereof, each said vertical pressure sensor array comprising a lower pressure sensor and an upper pressure sensor disposed in vertical spaced relation and means for maintaining vertical orientation of the vertical pressure sensor array; supplying an energy source in the vicinity of said vertical pressure sensor arrays; obtaining seismic data from said lower pressure sensor and said upper pressure sensor of each of said

vertical pressure sensor arrays; and processing said seismic data to discriminate between upgoing and downgoing wavefields produced by said energy source.

In another aspect, the invention relates to a method of obtaining marine seismic data, comprising the steps of:

deploying on the water bottom a cable having a plurality of vertical pressure sensor arrays connected at intervals thereof, each said vertical pressure sensor array comprising a lower pressure sensor, middle pressure sensor, and an upper pressure sensor disposed in vertical spaced relation and means for maintaining vertical orientation of the vertical pressure sensor array; supplying an energy source in the vicinity of said vertical pressure sensor arrays; obtaining seismic data from said lower pressure sensor, said middle pressure sensor, and said upper pressure sensor of each of said vertical pressure sensor arrays; and processing said seismic data to discriminate between upgoing and downgoing wavefields produced by said energy source.

Brief Description of the Drawings

Fig. 1 is an illustration of a conventional streamer technique;

Fig. 2 is an illustration of a conventional bottom-referenced cable technique;

Figs. 3a and 3b are graphs illustrating hydrophone and geophone response at the water bottom;

Fig. 4a is an illustration of a bottom-referenced cable using vertical pressure sensor arrays in accordance with the present invention;

Fig. 4b is a top view of a plurality of bottom-referenced cables in accordance with the embodiment of Fig. 4a.

Fig. 5 is an enlarged view of a vertical hydrophone array employing two hydrophones;

Fig. 6 is an enlarged view of a vertical hydrophone array employing three hydrophones; and

Fig. 7 illustrates discrimination between upgoing and downgoing wavefields using a bottom-referenced cable having vertical hydrophone arrays in accordance with the invention.

Description of the Preferred Embodiments

Preferred embodiments of the invention will now be described with reference to the accompanying drawings.

A bottom-referenced cable for marine seismic exploration using vertical arrays of pressure sensors in accordance with the present invention is shown in Fig. 4. The pressure sensors may be hydrophones, as they will be referred to below, or any other suitable pressure sensor.

As with the conventional bottom-referenced cable technique shown in Fig. 2, an energy source 19 is provided from the vessel 15, and the bottom-referenced cable 41 is deployed on the sea floor by one or more vessels 33.

Typically, a plurality of cables 41 will be deployed to form an array as shown in top-view in Fig. 4b. The cables 41 are deployed to avoid structures such as platforms 44. A plurality of take-outs 43 are provided at intervals along each cable 41. Vertical arrays 45 of two or more hydrophones (two shown in Fig. 4a) are provided at each take-out. As shown in more detail in Fig. 5, each array 45 includes a vertical cable 46 suspended from a float 47. At least two hydrophones, an upper hydrophone 49_U and a lower hydrophone 49_L, are disposed at intermediate locations along cable 46 between the float 47 and the bottom cable 41. Typically, the distance Dl between the lower hydrophone 49_L and the cable 41 is approximately one meter, and the spacing D2 between the upper and lower hydrophones is 6 to 8 meters.

Fig. 6 illustrates an array 45 having three hydrophones: upper hydrophone 49_U,

middle hydrophone 49_M and lower hydrophone 49_L. In this embodiment, distance Dl is typically of the order of 1 meter, and distances D2 and D3 are equal, usually in the range of 6 to 8 meters. Any number of hydrophones greater than one can be used in the array. Also, multiple hydrophones may be used at each location for redundancy.

Each hydrophone in the array 45 is preferably connected to a separate channel, and the hydrophone array is decoupled from the cable 41 and from the float 47 by vibration isolators 46 to prevent induced noise due to vibrations. The distance between arrays 45 along the cable 41 is typically 12.5 meters, 25 meters, or 50 meters.

Fig. 7 illustrates operation of the present invention and, for purposes of clarity, shows only a single vertical hydrophone array 45 disposed on a single bottom cable 41. It can be seen from this illustration that the primary wave 23 reflected off subsurface formation 21 is received by the lower hydrophone 49_L before it is received by the upper hydrophone 49_U. Ghost wave 25, which is a downward-travelling wave from the air/water boundary 13, is received by the upper hydrophone 49_U before it is received by the lower hydrophone 49_L. This difference allows discrimination between upward-travelling and downward-travelling waves, and thus permits virtual elimination of the ghost signals.

When two hydrophones are used in the vertical array, the seismic waves detected at the upper and lower hydrophones are combined to form a sum and a difference. The difference is then integrated, scaled, and combined with the sum signal. The result maybe used to obtain either an upgoing or a downgoing seismic signal, and has the appearance of originating from a hydrophone position located midway between the vertically spaced hydrophones.

More specifically, when two hydrophones are used per array, the reference level for processing is a hypothetical hydrophone located midway between the two vertically separated hydrophones. The seismic trace recorded by that hydrophone is "middle (t)", where t is the time. The seismic trace recorded by the upper hydrophone is "over (t)",and the seismic trace recorded by the lower hydrophone is "under (t)". These traces can be expressed in the following ways:

$$\text{middle}(t) = U(t) + D(t) \qquad (1)$$

wherein U(t) is the upgoing wavefield and D(t) is the downgoing wavefield;

$$\text{over}(t) = U(t + dt) + D(t - dt); \text{ and} \qquad (2)$$

$$\text{under}(t) = U(t - dt) + D(t + dt), \qquad (3)$$

where dt is one-half the travel time between the actual receiver positions. Equations (2) and (3) can be expanded using the Taylor series expansion in dt, which is illustrated below in equations (4) through (7):

$$U(t + dt) = U(t) + \dot{U}(t) * dt + \text{other terms} \qquad (4)$$

$$D(t + dt) = D(t) + D(t) * dt + \text{other terms} \qquad (5)$$

$$U(t - dt) = U(t) - U(t) * dt + \text{other terms} \qquad (6)$$

$$D(t - dt) = D(t) - D(t) * dt + \text{other terms}. \qquad (7)$$

Equations (2) and (3) can be rewritten using equations(4)-(7) and by limiting the Taylor series expansion to one term:

$$\text{over}(t) = U(t) + U'(t)dt + D(t) - D'(t)dt \qquad (8)$$

$$\text{under}(t) = U(t) - U'(d)dt + D(t) + D'(t)dt. \qquad (9)$$

Sum and difference traces are then computed:

$$\text{sum}(t) = 2U(t) + 2D(t) \qquad (10)$$

$$\text{dif}(t) = -2U'(t)dt + 2D'(t)dt \qquad (11)$$

The difference is integrated:

$$\text{intdif}(t) = -2U(t)dt + 2D(t)dt. \qquad (12)$$

From equations (10) and (12), it is possible to solve for the upgoing wavefield U(t) or for the downgoing wavefield

$$D(t) = \{\text{sum}(t) + (1/dt)\text{intdif}(t)\} / 4 \qquad (13)$$

$$U(t) = \{\text{sum}(t) - (l/dt)\text{intdif}(t)\} / 4. \qquad (14)$$

The factor l/dt is a function of the separation of the hydrophones and the velocity of propagations between them. In practice this factor can be determined by balancing the power

in the sum and the integrated difference traces.

When three hydrophones are used in the vertical array, the reference level is the middle hydrophone. The seismic signal recorded from the middle hydrophone is subtracted from the seismic signal recorded at the upper hydrophone. The seismic signal recorded at the lower hydrophone is subtracted from the seismic signal recorded at the middle hydrophone. These two difference signals are then integrated and the integrated differences are summed together. The resulting sum is combined with the seismic signals recorded by the middle hydrophone, thus allowing either the upgoing or the downgoing wavefield to be obtained. The resultant signal appears as a signal obtained from the middle hydrophone, and has increased resolution over the signal obtained using only two hydrophones in the array.

The vertical hydrophone array with three hydrophones is illustrated in Fig. 6. The expression of the seismic traces recorded by the upper (over) , middle, and lower (under) hydrophones can be in terms of the upgoing and downgoing wavefields recorded at the middle-hydrophone:

$$\text{over}(t) = U(t + dt) + d(t - dt) \tag{15}$$

$$\text{middle}(t) = U(t) + D(t) \tag{16}$$

$$\text{under}(t) = U(t - dt) + D(t + dt). \tag{17}$$

By using a Taylor series expansion in dt with two terms, equations (15)-(17) can be written as:

$$\text{over}(t)=U(t)+U'(t)dt+(dt*dt/2)U''(t)+D(t)-D'(t)dt+(dt*dt/2)D''(t) \tag{18}$$

$$\text{middle}(t) = U(t) + D(t) \tag{19}$$

$$\text{under}(t)=U(t)-dtU'(t)+(dt*dt/2)U''(t)+D(t)+D'(t)dt+(dt*dt/2)D''(t). \tag{20}$$

The difference traces over-middle and middle-under are calculated in equations (21) and (22):

$$\text{over-middle}=dtU'(t)+(dt*dt/2)U''(t)-dtU'(t) \tag{21}$$

$$+(dt*dt/2)D''(t)$$

$$\text{middle-under}=dtU'(t)-(dt*dt/2)U''(t)-dtD'(t) \tag{22}$$

$$-(dt*dt/2)D''(t).$$

The differences (21) and (22)are then integrated to obtain:

$$A=\text{int}(\text{over-middle})=dtU(t)+(dt*dt/2)U'(t)- \tag{23}$$

$$dtD(t)+(dt*dt/2)D'(t)$$

$$B=\text{int}(\text{middle-under})=dtU(t)-(dt*dt/2)U'(t)- \tag{24}$$

$$dtD(t)-(dt*dt/2)D'(t)$$

Equations (23) and (24) are summed together to obtain: $A + B = 2dtU(t) - 2dtD(t)$. (25)

Equations (19) and (25) can then solved for the upgoing wavefield U(t) and for the downgoing wavefield D(t):

$$U(t) = (A+B) / (4*dt) + \text{middle}(t)/2 \tag{26}$$

$$D(t) = \text{middle}(t)/2 - (A+B) / (4*dt). \tag{27}$$

The bottom-referenced cable using vertical hydrophone arrays has various advantages over the prior art bottom-referenced cable using hydrophones and geophones. For example, because the hydrophones are perfectly coupled with the water, have the same signal to noise characteristics, and have the same sensitivity, the difficulties encountered in combining the dissimilar and variable geophone signals with the hydrophone signals are avoided. Further, the wavefield separation technique for the vertical hydrophone array is more robust than the wavefield separation method for the geophone/hydrophone combination in the conventional cable, and because of the increased resolution, the data recorded using the bottom cable with vertical hydrophone arrays the data can be perfectly merged with streamer

data after the wavefield separation and static corrections are applied.

Various embodiments of the invention have been shown and described. However, the invention is not so limited, but rather is limited only by the scope of the appended claims.

CLAIMS

1. A bottom-referenced cable system for marine seismic exploration, comprising:

a bottom-referenced cable adapted to be deployed on the water bottom; and

a plurality of vertical pressure sensor arrays connected to said cable, each said vertical pressure sensor array comprising:

a lower pressure sensor and an upper pressure sensor disposed in vertical spaced relation, and

means for maintaining vertical orientation of said vertical pressure sensor array.

2. The system of claim 1, wherein said means comprises a float.

3. The system of claim 1 or claim 2, wherein the vertical spacing between said upper pressure sensor and said lower pressure sensor is in the range of six to eight meters.

4. The system of claim 1or claim 2, further comprising a middle pressure sensor disposed in vertical spaced relation between said lower pressure sensor and said upper pressure sensor.

5. The system of claim 4, wherein the vertical spacing between said lower pressure sensor and said middle pressure sensor and between said middle pressure sensor and said upper pressure sensor is in the range of six to eight meters.

6. The system of any preceding claim, wherein said cable has a plurality of channels, and each of said pressure sensors is coupled to a separate channel of said cable.

7. The system of any preceding claim, wherein each of said pressure sensors comprises at least one hydrophone.

8. A method of obtaining marine seismic data, the method comprising the steps of:

deploying on the water bottom a cable having a plurality of vertical pressure sensor arrays connected at intervals thereof, each said vertical pressure sensor array

comprising a lower pressure sensor and an upper pressure sensor disposed in vertical spaced relation and means for maintaining vertical orientation of the vertical pressure sensor array;

supplying an energy source in the vicinity of said vertical pressure sensor arrays;

obtaining seismic data from said lower pressure sensor and said upper pressure sensor of each of said vertical pressure sensor arrays; and

processing said seismic data to discriminate between upgoing and downgoing wavefields produced by said energy source.

9. The method of claim 8, wherein said processing step comprises, for each said vertical pressure sensor array, the steps of:

combining the seismic data obtained from the upper pressure sensor with the seismic data from the lower pressure sensor to form a sum and a difference;

integrating and scaling said difference; and

combining the integrated, scaled difference with said sum to distinguish between the upgoing and downgoing wavefields.

10. A method of obtaining marine seismic data, the method comprising the steps of:

deploying on the water bottom a cable having a plurality of vertical pressure sensor arrays connected at intervals thereof, each said vertical pressure sensor array comprising a lower pressure sensor, a middle pressure sensor, and an upper pressure sensor disposed in vertical spaced relation and means for maintaining vertical orientation of the vertical pressure sensor array;

supplying an energy source in the vicinity of said vertical pressure sensor arrays;

obtaining seismic data from said lower pressure sensor, said middle pressure sensor and said upper pressure sensor of each of said vertical pressure sensor arrays; and

processing said seismic data to discriminate between upgoing and downgoing wavefields produced by said energy source.

11. The method claimed of claim 10, wherein said step of processing comprises, for each said vertical pressure sensor array, the steps of:

subtracting the seismic data obtained from the middle pressure sensor from the seismic data obtained from the upper pressure sensor to obtain a first difference;

subtracting the seismic data obtained from the lower pressure sensor from the seismic data obtained from the middle pressure sensor to obtain a second difference;

integrating said first difference and said second difference and summing together the integrated differences; and

combining said summed, integrated differences with the seismic data obtained from the middle pressure sensor to discriminate between the upgoing and downgoing wavefields.

12. The method of any one of claims 8 to 11, further comprising deploying a plurality of said cables on the water bottom.

Fig.1. Prior Art.

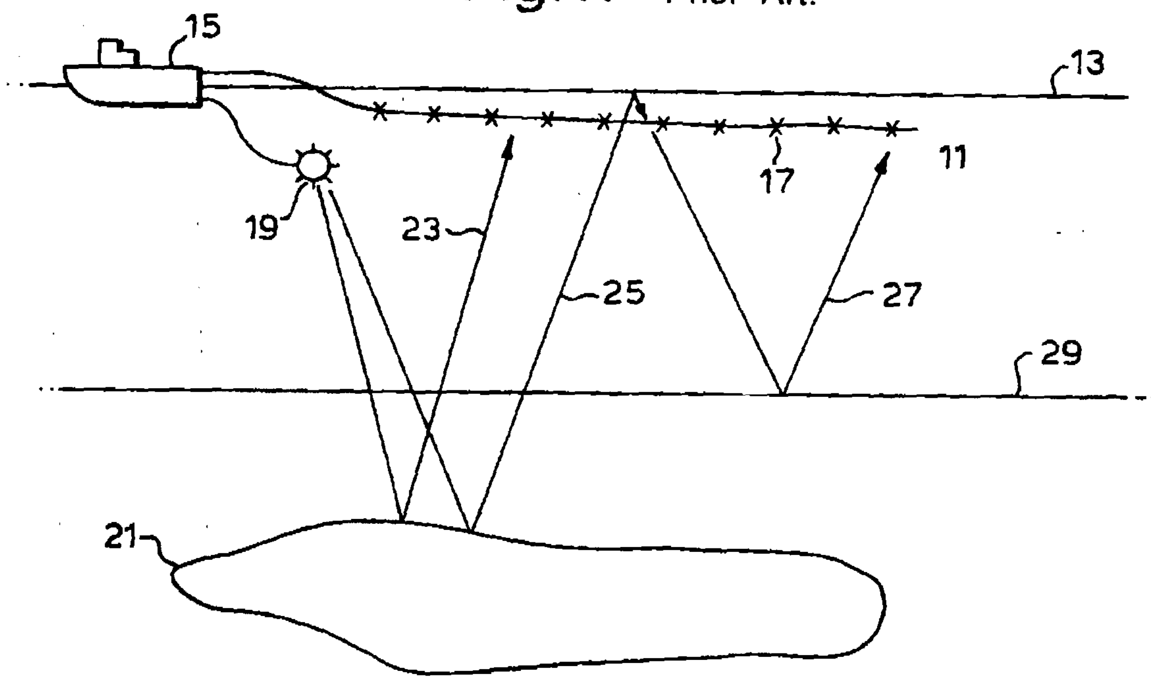


Fig.2. Prior Art.

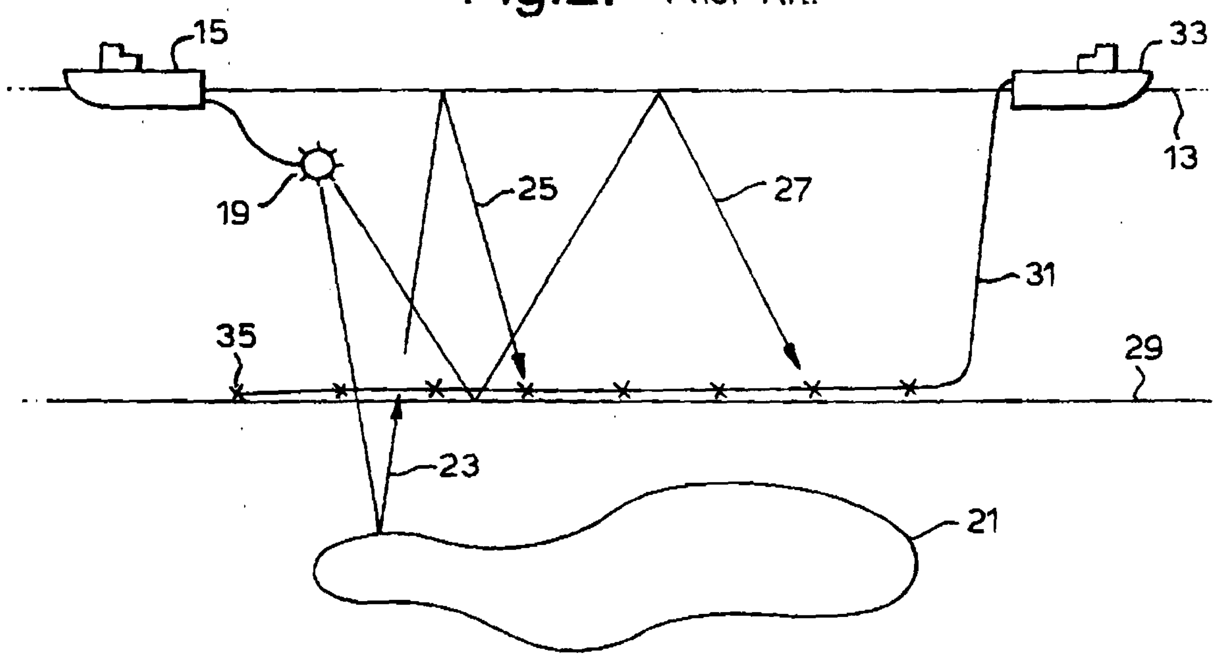


Fig.3a.

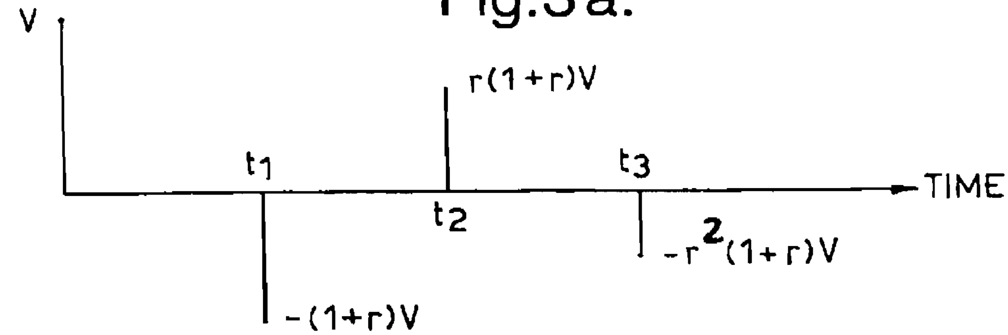


Fig.3b.

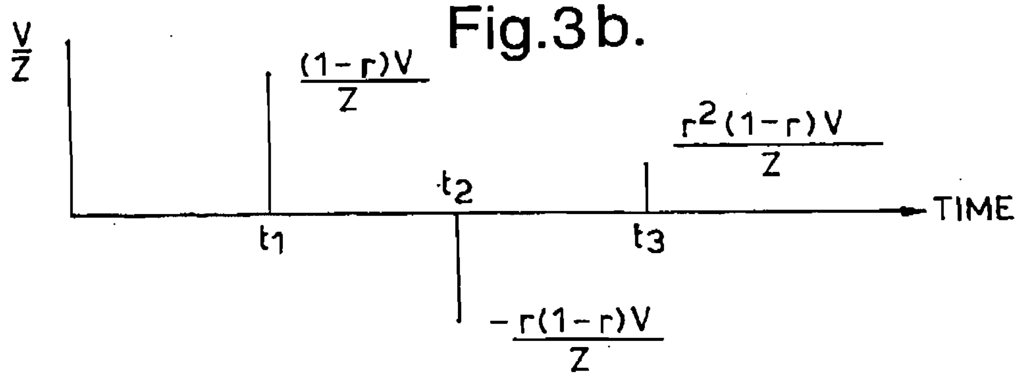


Fig.4a

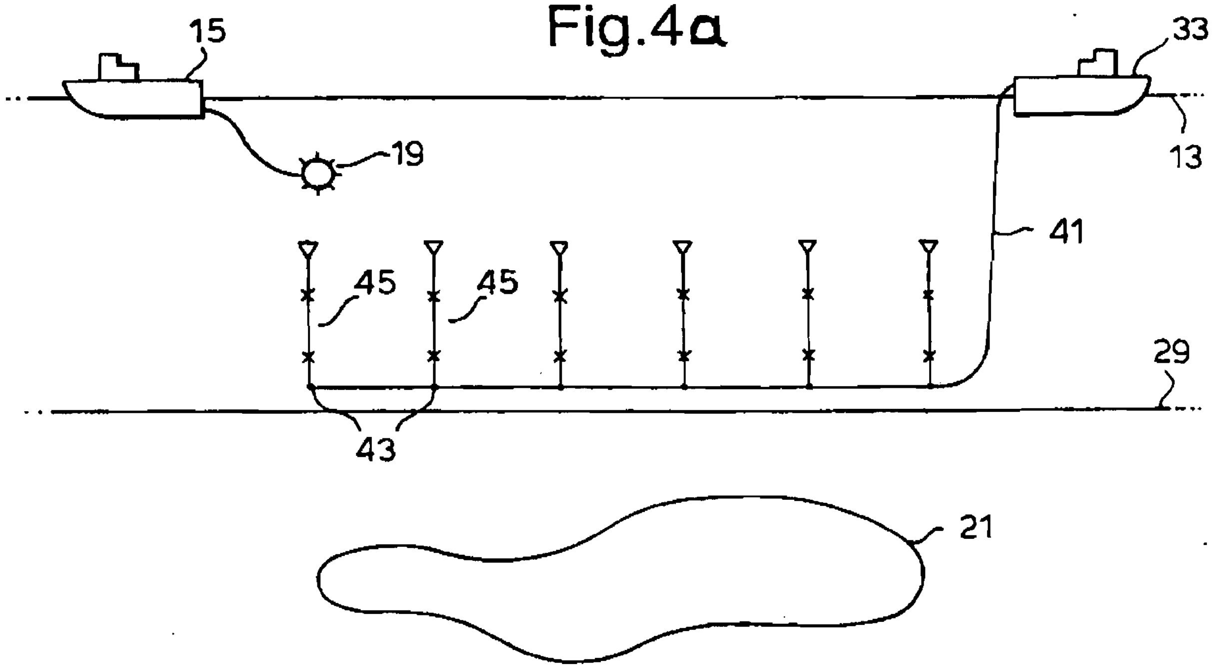


Fig.4b.

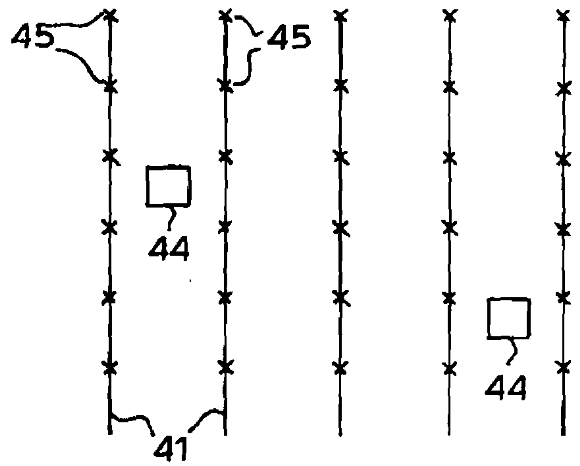


Fig.5.

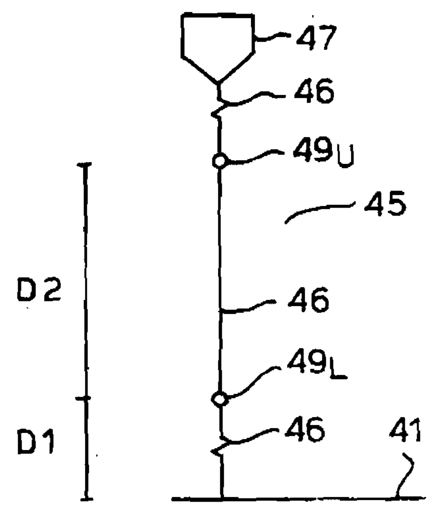


Fig.6.

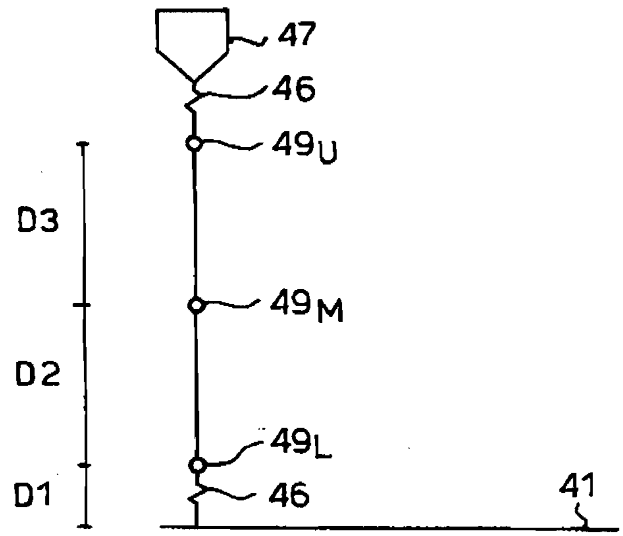
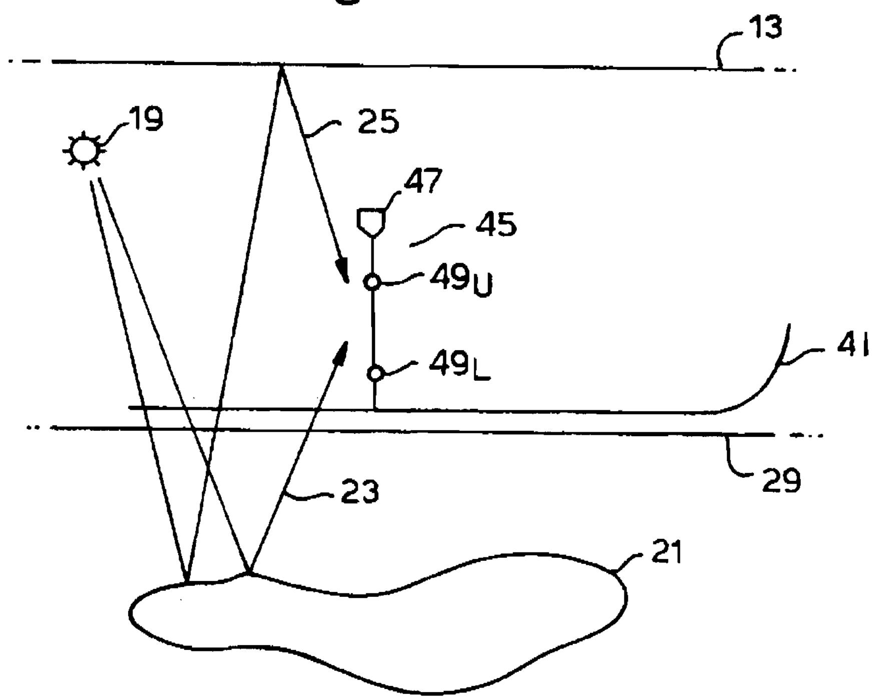


Fig.7.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 97/00309

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01V1/38 G01V1/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 235 554 A (BARR FREDERICK J ET AL) 10 August 1993 cited in the application see figure 1	1,7
A	US 5 452 266 A (CARTER G CLIFFORD) 19 September 1995 see abstract; figure 1	1
A	FR 1 458 272 A (COMPAGNIE DES COMPTEURS) 3 October 1966 see page 2, column 2, line 37 - page 3, column 1, line 12; figures 2,3	1,8,10
A	US 3 952 281 A (PARRACK ALVIN L) 20 April 1976 see claim 1; figure 4	1,8,10

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 July 1997	18.07.97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Anderson, A

INTERNATIONAL SEARCH REPORT

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PCT/IB 97/00309

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 1 193 507 A (INSTITUT FRANÇAIS DU PETROLE DES CARBURANTS ET LUBRIFIANTS) 3 June 1970 see page 5, column 2, line 117 - page 6, column 1, line 16 see page 6, column 2, line 96 - line 107; figures 5,9 ---	1,3-6
A	US 3 346 838 A (W.P. JONHSON III ET AL) 10 October 1967 see figures 4,5 -----	1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5235554 A	10-08-93	NONE	
US 5452266 A	19-09-95	NONE	
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		FR 93402 E	28-03-69
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		OA 2598 A	05-05-70
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